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ON VARIATIONS IN THE CONDUCTIVITY OF AIR ENCLOSED IN METALLIC RECEIVERS

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Communicated by Professor J. C. McLENNAN

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VII.—*On Variations in the Conductivity of Air enclosed in Metallic Receivers.*

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(Communicated by Professor J. C. McLennan, and read May 26th, 1908.)

I.—INTRODUCTION.

In a paper in the *Philosophical Magazine* of December, 1907, Professor McLennan records some observations made on the ionization of air enclosed in cylindrical receivers of lead, zinc, and aluminium. For "q," the number of ions generated per cc. per sec., in these receivers he obtained the value 15, when they were made of zinc and aluminium; while with lead, values were found ranging all the way from 23 to 160 ions per cc. per sec., depending on the sample of lead from which the cylinder was made. From these results, Prof. McLennan drew the conclusion that ordinary commercial lead contained in general varying amounts of some active impurity.

From these and other experiments he pointed out also, that four possible causes must be considered as contributing to the ionization in the cylinders, viz.:—(1) penetrating radiation from the earth, (2) secondary rays excited by this type in the metal of the receivers, (3) radioactive impurities present in the metals, and (4) a possible intrinsic radiation from the metals themselves.

In view of the theoretical importance of ascertaining whether metals generally possessed any specific activity it was thought highly desirable to endeavour to obtain metals as free as possible from active impurities, and also to take observations on the conductivity of air enclosed in vessels made from them in localities and under conditions in which the penetrating radiation from the earth and the accompanying secondary radiation excited by it in the receiver, was very largely cut off, or at least reduced to a minimum.

Several attempts had been made during the last few years to find some efficient screen for the earth's radiation. Cooke, while making some measurements on the conductivity of the air enclosed in a brass cylinder, found a decrease of about 30 per cent when the cylinder was completely surrounded by large masses of lead. Shortly afterwards Elster and Geitel[1] observed a fall of 28 per cent in the conductivity

[1]Elster and Geitel, Phys. Zeit., Nov. 1, 1905, p. 753.

of air enclosed in an aluminium receiver when the apparatus was set up in a rock salt mine. Later still, Cooke[1] was able to reduce the ionization 12 per cent by immersing his cylinder in a reservoir of water to a depth of several feet. The greatest decrease, however, was that observed by McLennan and Burton,[2] who cut off 37 per cent of the conductivity of the air enclosed in a galvanized iron cylinder, by surrounding it with a layer of water drawn from Lake Ontario, 60 cms. thick. This last result, taken in conjunction with an observation by McLennan that Lake Ontario water contains no appreciable radioactive impurities, gave rise to the idea that possibly a large body of water, such as the lake itself, might furnish an efficient screen for the earth's radiation.

The object of the present investigation, therefore, was to observe the conductivity of the air confined in metallic vessels possessing little if any radioactive impurity and from the results to determine, if possible, what portion of the ionization was due to an intrinsic activity in the metal.

In carrying out the investigation, the conductivity of air confined in vessels of lead, zinc, and aluminium was measured at a number of points in the neighbourhood of Toronto, both on land and over the water of Lake Ontario, and it was found that while a uniformly low and steady value was obtained for the conductivity over the water at all depths beyond a few metres, values varying over a wide range were obtained for the ionization, in measurements made on land at different places and on different soils.

The lowest values for "q," the number of ions generated per cc. per sec. in air confined in the metallic cylinders, were obtained in measurements on the surface of the lake and on the top of large masses of sand on the lake shore. With a lead receiver, under these circumstances, the value 8.6 ions per cc. per sec. was obtained for "q," and with zinc and aluminium cylinders, under the same conditions, the values 6.00 and 6.55 respectively. These values, it will be seen from Table I, are considerably below those hitherto recorded for the conductivity obtained under any circumstances of air contained in closed metallic receivers.

[1]H. L. Cooke, Phil. Mag., 1903.

[2]McLennan and Burton, Phys. Rev., 3, 1903; Burton, Phys. Rev., 3, 1904.

TABLE I.

Receiver.	Observer.	q	Conditions.
Lead..........	Eve[1]	96	Observations in Physical Lab., McGill, Montreal, —unscreened.
Zinc..........	"	24	
Aluminium....	"	24	
Brass..........	H. L. Cooke[2]	13.6	Unscreened.
Brass..........	"	9.1	Screened by large masses of lead.
			Observations taken in basement of University Library, McGill.
Lead..........	McLennan[3]	23	Unscreened.
Zinc..........	"	15	Measurements made in old Physics department, University of Toronto.
Aluminium....	"	15	
Lead..........	Wright	8.6	Measurements made over the surface of Lake Ontario—receivers otherwise unscreened.
Zinc..........	"	6.0	
Aluminium....		6.55	

II.—Apparatus.

Measurements such as were contemplated on the ionization in metal receivers over the surface of the lake required the use of some instrument which would be portable and at the same time not easily put out of adjustment. The electroscope recently devised by C. T. R. Wilson was found to fulfil all the requirements.

The instrument, Fig. 1, consisted essentially of a gold leaf system G, insulated from the outer case by a quartz ring and suspended inside a similarly insulated inner case connected with a quartz Leyden jar of about 100 cms. capacity charged to a potential of —50 volts.

In making a measurement on the conductivity of the air with this instrument, the metal receiver was placed on top of the electroscope, as

[1]Eve., Phil. Mag., Sept., 1906.
[2]H. L. Cooke, Phil. Mag, p. 403, 1903.
[3]McLennan, Phil. Mag., Dec., 1907.

shown in Fig. 1, and supported on ebonite blocks so as not to be in electrical connection with the instrument proper. The receiver was then charged to any desired voltage and the current through the air observed by the charge which was communicated in a given time to the electrode carried by the gold leaf system.

The function of the compensator C, which consisted of a sliding tube condenser was to annul by its motion any charge the system acquired

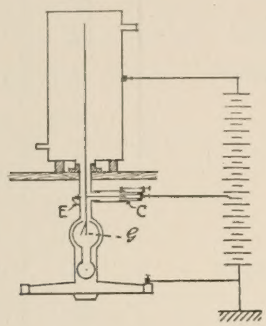

FIG. I

through the conductivity of the air in the receiver; this motion being so regulated as to keep the potential of the gold leaf always at zero, and thus minimize any tendency to promote a leak across the quartz insulation.

Thus, for a determination of "q." it was necessary only to know the charge annulled in the time during which the compensator moved a standard distance.

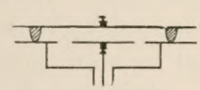

FIG. II

For a determination of the charge corresponding to this standard distance the parallel plate condenser shown in Fig. 2 was added in place of the electrode. The compensator tube was then charged to a known potential, giving for the total motion a certain deflection of the gold leaf; and the voltage on the upper condenser plate was then so adjusted as to bring the gold leaf back to its zero position. The charge could then be readily calculated from the dimensions of the parallel plate condenser and the voltage applied to it.

The corresponding values of voltage on compensator tube and charge annulled are given in Table II, and are illustrated by the curve in Fig 4.

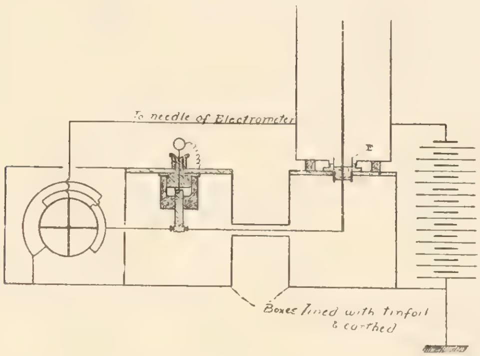

FIG 4

These values were determined experimentally and they showed that the capacity of the tube condenser was, as its construction demanded, practically independent of the voltage applied to it.

TABLE II.

Voltage on Compensator = V	Charge Annulled = E	E/V
	Electrostatic Units	Charge (E.S.U.) per volt
28.4	.1449	.00512
36.7	.1858	.00506
42.9	.2146	.00500
51.1	.2577	.00504
57.2	.2853	.00499
65.4	.3241	.00495
71.4	.3528	.00494
78.3	.3882	.00496
		Mean = .00501

From the following calculations it will be seen how the different constants of the instrument were used in making a determination of the value of "q" for the air contained in a certain lead receiver:

Reading of Compensator distance Scale Divisions (cms.)	Time.	Remarks.
.254	1′ 02″	Date of Experiment, Mar. 19th, 3 P.M.
.508	1′ 45	
.762	2′ 29	Locality — Basement of Physics Laboratory.
1.016	3′ 15	
1.270	4′ 05	Potential Applied to Cylinder = – 85 volts.
1.524	4′ 48	
1.778	5′ 33	Potential Applied to Compensator = — 13.0 volts.
2.032	6′ 17	
2.286	7′ 05	Vol. of Cylinder = 26700 ccs.
3.302	8′ 09	

From Table II, the charge annulled per volt on the compensator tube = .00501.

∴ total charge annulled in 489″ was

.06513 e.s. units

Thus $.06513 = 3.4 \times 10^{-10} \times q \times 489 \times 26700$

or $q = 14.67$ assuming the charge on an ion to be

3.4×10^{-10} E.S.U.'s.

As a check on the values for "q" obtained with the instrument for the ionization in the metallic receivers, determinations were alternately made in the laboratory with the Wilson electroscope and with a sensitive Dolazelek electrometer. The method of using the latter is shown in Fig. 3. With this arrangement it was possible by simply removing the receiver, unscrewing the electrode and slipping a metal cap over the earthed tube E, to allow for any charge acquired by the electrodes and the free quardrants through possible defective insulation of supports, or by conduction through the air in any part of the apparatus. other than through that in the metal receiver.

The capacity of the instrument was found by measuring in each determination of the conductivity, the rate of motion of the needle,

both with and without an auxiliary condenser of known capacity attached to the electrode.

To show how the determination of "q" with this instrument was arrived at and to give an estimation of the magnitudes involved, a measurement was undertaken with the same cylinder and under the same conditions as obtained in the case of the determination with the Wilson instrument, the actual values being given in Table III. These values for "q," as obtained with the two instruments, are seen to be practically the same and so afford a conclusive test of the accuracy of the measurements.

TABLE III.

(1)—Date Mar. 19, 4 p.m.

(2)—Lead Cylinder No. 1.

(3)—Locality—Basement of Physics Laboratory.

(4)—Potential applied to needle + 250 volts.

(5)—Rate of motion of needle without condenser = 13.0 mm. per min.

(6)—Rate of motion of needle with condenser = − 7.4 mm.

(7)—Rate of motion of needle due to defective insulation cylinder being removed and electrode capped = − 1.0 mm.

∴ Rate due to conduction in air in cylinder alone = − 12.0 mm.

(8)—Sensitiveness = 832.2 mm. per volt.

(9)—Capacity of auxiliary condenser = 128.04 cms.

(10)—Temp. 10°C, voltage on cylinder + 85.

(11)—Volume of cylinder = 26700 ccs.

From this we obtain:—

Capacity of electrometer 169.1 cms.

The calculation to determine "q" is then

$$\frac{169.1 \times 12}{832.2 \times 300} = q \times 3.4 \times 10^{-10} \times 60 \times 26700$$

Whence: $q = 14.93$

Before making the final measurements in these comparisons, preliminary observations were made to ascertain what voltage it was necessary to apply to a receiver in order to obtain saturation currents. A set of the different voltages applied and the corresponding values of the currents obtained with a lead cylinder of comparatively high activity. but having dimensions the same as cylinder No. 1 mentioned above, are given in Table IV and a curve to represent them in Fig. 6. From the latter it may be seen that a potential of 60 volts gave a reading well over the knee of the curve, and as the voltage applied in all the determinations lay between 80 and 250 volts, it is clear that saturation currents were always obtained.

TABLE IV.

Voltage on Receiver (positive.)	"q" = No. of ions. per cc. per sec.
2	13.6
4	21.3
6	26.2
8	29.3
11.2	33.3
17.7	37.8
34.0	40.8
47.0	41.6
63.3	42.9
81.6	42.9
163.2	43.3
251.2	44.2

III.—Some Special Observations with Lead Cylinders.

It will be remembered that Prof. McLennan in his investigation of last year drew the conclusion that ordinary commercial lead, in so far as he investigated it, contained in general an active impurity. Such being the case, one should expect a certain falling off in the course of time of the ionization in a lead receiver due to the decay of the activity. It was decided then to determine again the conductivity of air in certain lead receivers used by him in June last in his investigation to see whether any decrease from the former values could be noted. Lead cylinders, described as numbers 1, 2 and 3 in Prof. McLennan's paper, were used for this purpose, and the values of the ionization for each cylinder determined with both the electroscope and the electrometer. These numbers, which are given in Table V, show a considerable decrease in the value of "q" from the values for each receiver obtained by Prof. McLennan.

TABLE V.

Mar. 6th.

q_0 = Number of ions per cc. per sec. reduced to zero centigrade.

Lead Cylinder.	By Electroscope.	By Electrometer.	Values obtained by Prof. McLennan.
	"q_0"	"q_0"	"q"
No. 1.......	15.14	15.42	23.
No. 2.......	135.8	139.6	160.
No. 3.......	28.55	29.21	37.

This result seemed somewhat surprising in view of the fact that Prof. McLennan had obtained the same numbers repeatedly during a period of over six months. As the experiments made by the writer with the three lead cylinders were carried out in a room in the new physical laboratory, and those by him in one in the older building, it was thought well to make a redetermination in the latter, but, on doing this, it was found that a slightly lower value even was obtained for the ionization in the measurements taken in this room than in those in the new laboratory.

Although the experiments were made in a room supposed to be free, or far removed, from any active substances, it seems probable that there was in the old department, or in the rooms adjacent, some unobserved source of radiation present during Prof. McLennan's investigation which was absent during the measurements made by the writer, and this impurity was very probably removed when the old laboratory was vacated by the Department of Physics and adapted to other purposes.

It might be pointed out that the lowest value for "q" hitherto recorded for the ionization in a lead cylinder, even with this possible additional influence is that of 23 ions per cc. per sec., given by Professor McLennan. The present value of 15, obtained with this cylinder, is still lower, and would seem to indicate that we possessed in this lead receiver one which contained little if any impurity. It was, therefore, especially suitable, if proper screens could be found, for the investigation of any intrinsic activity associated with the metal lead itself.

IV.—Preliminary Observations on Conductivity.

(a)—General conditions of the different experiments—

It has been noted by Prof. McLennan and other observers that when a metallic receiver has been thoroughly scoured with emery or glass paper in order to remove any active coating which may have been deposited on its surface by exposure to the atmosphere, and after being washed with hydrochloric acid, ammonia, alcohol and distilled water,

then filled with freshly filtered air and allowed to stand, the ionization of the enclosed air gradually increases for some days and ultimately reaches a steady value. Owing to this effect it was found necessary in comparisons of the ionizing power of radiations existing in any two localities or under any two conditions to make the observations, with the ionization chamber under precisely the same conditions in both circumstances.

The different comparisons were made, therefore, either with a receiver freshly cleaned and freshly filled with filtered air immediately before taking the observations, or else with a receiver containing air which had been allowed to remain in it till the steady state had been reached.

Further, as it was impossible always to obtain observations at different times with the atmospheric conditions the same as to pressure and temperature, it was assumed that the ionization obtained in all localities would vary directly with the density of the air in the receiver, and in making any reductions which were necessary in order to reach values which were comparable, assumption, which is amply warranted by the measurements of McLennan and Burton [1] on the ionization of air at different pressures, has been adopted.

In this connection it may be well to emphasize the extreme importance of taking every precaution in making observations such as are described in the present paper, to secure absolute uniformity in the conditions of the measuring receivers. With the different receivers used in the present investigation it was found that when the cylinders were thoroughly scoured and washed in the manner described above, the conductivity of freshly filtered air admitted into the chamber was always the same at any particular observing station, and thus, by always working under these definite conditions, it was possible to obtain very definite results.

Numerous investigators in this field of research have experienced considerable difficulty in arriving at concordant results, but if the precautions mentioned are taken, it is possible to obtain a thoroughly reliable value for the conductivity of air enclosed in any metal receiver.

(*b*)—*Daily variation in the conductivity of atmospheric air.*

Among other investigators, Wood and Campbell,[2] McKeon [3] and Strong [4] have observed daily variations in the conductivity of air confined in metallic vessels, and, inasmuch as it was not practicable to take observations in different localities at the same time of day in the

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[1] McLennan and Burton, Phys. Rev. (3), 1903.
[2] Wood and Campbell, Phil. Mag., Feb., 1907.
[3] McKeon, Phys. Rev., Nov., 1907.
[4] Strong, Phys. Zeit., Feb. 15, 1908.

present investigation, a number of preliminary sets of observations was made throughout different days in a room in the Physics Building on the conductivity of the air confined in a lead receiver, in order to obtain evidence of the daily variation, and also, if such existed, to obtain an estimate of its magnitude.

Two sets of continuous readings taken in this way with the air in a lead cylinder in the steady state mentioned above, are given in Table VI, and from the values quoted it will be seen that there is no evidence of any appreciable regular variation in the conductivity. It is to be noted, too, that the extreme values obtained did not differ from the mean conductivity by more than 3 per cent of the latter.

TABLE VI.

Lead Cylinder 1, in steady state. Voltage on Cylinder—83.

Time.		q° = number of ions per cc. per sec. reduced to 0° C.
Dec. 24th—	10.23 A.M.	22.48
	10.43	22.51
	11.10	22.54
	11.32	22.45
	11.55	21.74
	12.15 P.M.	22.73
	12.40	21.96
	1.00	22.94
Dec. 26th—	9.35 A.M.	22.44
	9.58	21.86
	10.20	21.87
	10.45	22.25
	11.05	22.96
	11.28	22.79
	11.50	22.53
	3.55 P.M.	22.65
	4.15	22.54
	4.40	22.94
		Mean = 22.45

In the results which will be given later it will be seen that variations amounting to as much as 75 per cent were obtained in the conductivity by a change in the observing station, and from the results obtained and given in Tables IX, X and XI it will be seen that any variation in conductivity due to daily changes in the value of the penetrating radiation from the earth which might have existed, were negligible in comparison with the variation in the conductivity due to a change in the point of observation.

(c)—Secondary radiation from the walls of a room.

In view of the existence of a penetrating radiation at the surface of the earth having its origin either in the atmosphere or in the soil. and in view of the production by such radiations of secondary rays at the surface of substances traversed by them, it was thought advisable, before going on with the main part of the investigation, to see how far the influence of a secondary radiation excited in the walls of a room could be detected from those walls.

To obtain some information on this point, two plans suggested themselves,—(1) to place the conductivity chamber at a selected distance from a wall and to study the secondary rays excited at that wall by a quantity of radium placed at points on a circle with the chamber at its centre; (2) to study the variation in the ionization in a metal receiver with the radium at a fixed distance from the wall and the chamber placed at points on a circle with the radium as centre. A set of measurements was made by following the first plan, but time has not permitted the carrying out of a series of observations with the second arrangement.

The electroscope, provided with a zinc receiver, in these measurements was placed at a distance of about one metre from the wall of a large room, and the radium enclosed in a lead box with walls 2 cms. in thickness, was moved around the circumference of a circle having as centre the cylinder and as radius the distance of the same from the wall.

The values for "n," the number of ions per c.c. per sec. due to the primary radiations from the radium, as well as the radiation emitted by the brick wall, together with the corresponding secondary rays excited in the metallic cylinder, are given in Table VII, and shew a regular decrease in the ionization as the distance of the radium from the wall was increased, with indications of a possible smaller maximum for a definite angle subtended at the wall by the line joining the radium with the electroscope. A curve representing the variation of "n" with the distance of the radium from the wall is given in Fig. 6. From

these results it is clear that for all positions of the radium a secondary radiation of considerable intensity was emitted by the brick wall under the excitation of the rays from the radium.

TABLE VII.

Cylinder of zinc.
Potential of cylinder = 250 volts, positive.
Radius of circle on which radium was placed, about 1 metre.

Distance of radium from wall (cms).	Ionisation (arbitrary scale).
5.5 cms.	72.93
10.0	71.74
16.2	69.16
23.4	69.83
28.6	69.16
63.6	67.94
98.0	66.31
146.0	65.70
5.5	72.93

In order to obtain further information regarding this secondary radiation the instrument provided with an aluminium cylinder was moved to one of the corners of the room and a similar set of observations made, the values obtained for "n" in this case being given in Table VIII, and illustrated by the curves in Fig. 7.

TABLE VIII.

Distance of aluminium receiver from far wall = 300 cms.
Distance of aluminium receiver from near wall = 105.5 cms.
Potential of receiver = 250 volts positive.
Radium placed on circle 100 cms. radius, with receiver at centre.

Distance of radium from near wall.	Ionisation (arbitrary scale.)
5.5	51.86
10.9	50.89
20.	50.68
41.4	49.95
55.1	49.13
76.4	49.80
110.9	50.63
153.7	50.00
197.	48.08

There again it is seen that the effect of the secondary radiation was quite marked. As the results show the ionization steadily decreased to a minimum value which corresponded approximately to the position in which the radium was on the line joining the electroscope to the corner of the room. After passing through this minimum value the ionization then steadily increased and reached a maximum when the radium was slightly beyond a line drawn from the cylinder perpendicular to the far wall. After this the ionization fell away again as the distance of the radium from both walls was increased.

The maximum variation in the values of "n" for these experiments, it will be seen from Tables VII and VIII amounted to as much as 10 per cent. It seemed reasonable, therefore, to suppose that the presence of some such object as a brick wall might, when the penetrating rays from the earth impinged upon it, in the same way affect the natural ionization in any metallic cylinder, and care was, therefore, taken in the measurements made when determining the screening effect of the lake and of different soils, to place the electroscope and receiver as far away as possible from any building which might modify in some such way as that indicated the ionization of the enclosed air.

V.—Screening Experiments.

Being assured from the foregoing experiments that changes in the ionization due to daily variations were inconsiderable in comparison with variations due to a change in position, three series of measurements were then undertaken with the object of investigating the screening effect of Lake Ontario, care being taken to choose positions of observation as far as possible from any artificial surroundings. The first and second series were made with lead cylinders after the ionization had reached the steady state and the third with well cleaned cylinders of lead, zinc and aluminium containing freshly filtered air. A considerable decrease in the ionization when measured over the water was noticeable in every case, a reduction of as high as 60 per cent being recorded in the case of the freshly cleaned lead cylinder in the third series of measurements referred to above.

1.—*Measurements on board steamer "Corona."*

In the first set of measurements a series of observations was made on a selected day in the laboratory on the conductivity of the air enclosed in a lead receiver which had not been recently cleaned, and the mean of these readings was found to give a value of 42 ions per c.c. per sec. for the conductivity. Measurements were then made on the same day on board the SS. "Corona" during one of her voyages, and

also at a number of points on land on the south side of Lake Ontario, between Queenston Heights and Niagara Falls. These results are recorded in Table IX.

TABLE IX.

Comparison of conductivity experiments made on Steamer "Corona" with those made on land.

"q_0" = Number of ions generated per cc. per sec. at O°C.	Locality.
41.7 (mean value)	Physical Laboratory.
34.9 35.6 35.2	On board "Corona" outward trip.
43.3	Queenston Heights.
42.4	Pavilion Niagara Falls Park.
42.	Tunnel of Ontario Power Co., 42 metres underground.
35.9 35.5 36.5	On board "Corona" homeward trip.

Mean of results of land experiments = 42.3 ions per cc. per sec.
Mean of results of steamer experiments = 35.6 ions per cc. per sec.
Difference = 6.2 ions per cc. per sec.

From the table it will be seen that the ionization at different points on the limestone soil of the Niagara District was practically constant. It will be seen, too, that the ionization obtained about 42 metres underground at the Falls was practically the same as that obtained at the surface on the limestone ridge. We see also from the figures that the screening action of the lake minus any effect due to an intrinsic radiation from the boat itself is represented by the value of 6.7 ions per c.c. per sec. with the particular lead cylinder used. From the figures which are given later in Table X it will be seen that the screening effect of the lake in a cylinder of lead in the condition of that used in the above experiment is represented by 9 ions per c.c. per sec., which shows that approximately 2.3 ions per c.c. per sec. must have been due to a radiation emitted by the steamer or by its contents.

2.—*Measurements made along the waterfront of Toronto Bay.*

A second series of measurements was made with the lead cylinder referred to in the first portion of the paper as No. 1, after it had reached what has been referred to above as the steady condition, observations on the ionization being taken at different points along the water front of Toronto Bay.

The results given in Table X shew a total decrease of 9 ions per c.c. per sec. from the value of "q" obtained in the laboratory, due to the screening action of the water, and they seem to indicate in addition that the ionization over sand banks washed up by the waves was but little greater than that over water even of a considerable depth.

TABLE X.

Dec. 28th.

Lead Cylinder 1, in steady state.

"q_0" = number of ions per c.c. per sec. (mean value.)	Locality.
22.5	Laboratory of new Physics Building.
19.3	Under York St. Bridge—"made land," 30 m. from water.
14.1	South end of west side of Eastern Gap, 3.40 m. from shore; water 4.6 m. deep.
14.2	Sand spit of Ward's Island, 110 m. from shore.
13.5	Toronto Canoe Club House. Light pine structure on piles. Water 5.6 m. deep.

This result is probably due to the fact that any radioactive substances originally present in the sand have been washed away by the action of water.

In this connection it is important to note that in making these determinations of the conductivity of air enclosed in lead receivers it was frequently observed that in the measurements on the surface of the lake with newly cleaned lead cylinders, filled with freshly filtered air, the drop in conductivity observed was invariably about 50 per cent less than the drop obtained with lead cylinders which, after being well cleaned and filled with clean air, had been allowed to stand long enough to reach the steady state.

This difference in the drop in conductivity is well illustrated by the results obtained with the lead cylinder No. 1. With this cylinder in the steady state, as the numbers in Table X shew, the conductivity when measured in the laboratory corresponded to the generation of 22.5 ions per c.c. per sec. With the same cylinder freshly cleaned and filled with well filtered air the conductivity, as measured in the same room in the laboratory always corresponded to the generation of approximately 15.3 ions per c.c. per second. In the measurements on the surface of the lake water, however, the conductivity corresponded to the generation of 13.9 ions per c.c. per second when the cylinder was in the steady state, while, as will be seen from the results recorded in the next section, it corresponded to the generation of only 8.5 ions per c.c. per second when the cylinder had been freshly cleaned and filled with filtered air.

This difference in the values obtained for the drop in conductivity with the lead cylinder in the two conditions can no doubt be traced to differences in the secondary radiation excited in the walls of the vessels by the penetrating radiation from the earth.

It is clear that the surface of the lead after being freshly cleaned must have gradually become covered with a deposit through oxidation and other causes, and it is reasonable to conclude that the presence of this deposit would produce such a modification in the intensity of the secondary radiation as to bring about the results described.

3.—*Measurements made in different localities and with different receivers freshly cleaned.*

The preliminary measurements just described made it abundantly evident that the lake water acted as a very efficient screen for the earth's radiation, a maximum decrease in the value of "q," of as much as 9 ions being recorded in the last series of observations. A careful set of measurements was therefore undertaken, having for its object a determination of the relative decrease in the values of "q" over water from those obtained in the laboratory, when freshly cleaned receivers of lead, zinc and aluminium were used in turn as the containing vessels. In the case of the lead cylinder the conductivity was measured at a larger number of points to determine if possible in what way the ionization was influenced by external conditions such as a change of soil.

The results, which are in many cases the mean of a number of observed values obtained on different occasions and differing but slightly from one another, are given in Table XI.

TABLE XI.

Observation Station Number of Location Station.	Remarks.	Value of "q", the no. of ions generated per cc. per second.		
		Lead.	Zinc.	Aluminum
1. The ice on Toronto Bay, 100 metres from the Yacht Club Wharf.	Water, 10 metres deep.............. Ice, 30 cms. thick.	9.0	....	....
2. The ice near Canoe Club Wharf, Toronto Bay.	Water, 5.6 metres deep.............. Ice, 30 cms. thick.	8.6	6.0	6.55
3. The ice on Grenadier Pond, an inlet of Lake Ontario, Station "a."	Water, 2.5 metres deep.............. Ice, 30 cms. thick.	9.2	....	....
4. The ice on Grenadier Pond, Station "b."	Water, 3.5 metres deep.............. Ice, 30 cms. thick.	9.0	....	....
5. At the shore of Grenadier Pond, Station "c."	....	9.1	....	....
6. On a sand hill overlooking Grenadier Pond.	Height of hill about 50 metres distance from shore, 100 metres	9.3	....	....
7. University Lawn.	Clay, soil, sodded, frozen and covered with ice and snow, 20 cms. deep	11.2	....	....
8. University Tower.	26 metres high......	11.4	....	....
9. In the open on the ground in the rear of the new Physical Laboratory.	Frozen clay, recently overturned, covered with 10 cms. of ice and snow	13.2	11.1	10.4
10. A room in the basement of the new Physical Laboratory.	As the building is new, it was supposed to be free from any radioactive contamination.........	15.3	13.4	12.5

From the observations with the lead cylinder it will be seen that the ionization obtained over water of different depths was practically constant, the value for "q" being, as before, but slightly less than that obtained above a sandy soil. It is important to note also that the ionization on top of the university tower was the same as that found below on the campus, indicating that the atmosphere could not be the source of the penetrating radiation which gave the variation noted in the values of "q" for the air confined in a closed metallic receiver.

From the values of "q," given in Table XI, for the three receivers, we obtain for the difference between the ionization in the laboratory and over the water the numbers 6.7, 7.4 and 6.0 for the receivers of lead, zinc and aluminium respectively. These values then may be taken as given by a measure of the relative ionization in the three receivers due to that portion of the radiation from the earth which was cut off by the water, together with the secondary rays induced by the radiation in the different cylinders. That the actual numbers obtained for "q" at any observing station were not in the same ratio as these decreases is a conclusive proof that the ionization measured at these stations was not due entirely to the radiation from the earth.

It might be well to call attention again to the fact that these decreases in the receivers of lead, zinc and aluminium of 6.7, 7.4 and 6.0, which are in the ratio of 1.1 to 1.23 to 1.00, must give a true measure of the total ionization in the three receivers which is due to a portion, at least, if not the whole of the penetrating radiation from the earth. If then we could obtain cylinders of lead, zinc and aluminium free from active impurities and possessing no intrinsic activity, we should expect the values for "q" at every point on the surface of the earth to be in this ratio.

Emphasis might also be laid upon the extremely low values found for the ionization over the water when the cylinders were freshly cleaned and freshly filled with filtered air. These values of 8.6, 6 and 6.5 obtained for the receivers of lead, zinc and aluminium are very much lower than those obtained by any other observer under any conditions, and afford a conclusive proof of the efficacy of Lake Ontario water as a screen for the earth's penetrating radiation.

The experiments made at Stations 5 and 6 are of special interest, as the conductivity obtained at these points was practically the same as that obtained in the experiments on the surface of the lake, which shows that the sand was entirely free from the radioactive substances which were probably present in the clays and rocks at other points of observation.

VI.—Secondary Rays Induced by the γ Rays from Radium.

To determine if this ratio of 1.1 to 1.23 to 1.0 for the three receivers of Pb., Zn. and Al. would be found to hold also in the case of ionization due to the γ rays from radium, a series of measurements was undertaken with the electrometer used before.

A quantity of radium bromide encased in a lead box with walls 2 cms. thick, was used as the source of the penetrating rays, and the ionization measured in each receiver for different distances between it

and the radium. The difference between the ionization before and after the radium was placed in position was recorded as due to the primary rays from the radium together with the secondary rays excited by them in the receiver. From Table XII it will be seen that " n," the value of the ionization in each receiver due to the presence of the radium, varied inversely as the square of the distance " d " from the cylinder, the same variation being shown graphically in Fig. 8. In this connection it may be noted, however, that for distances less than three metres a much larger value for " n " was obtained than was demanded by the law of the inverse square.

TABLE XII.

d= Distance of Radium from Cylinder. (Metres.)	Lead.	I	Zinc.	I	Aluminium.	
	" n "	nd^2	n	nd^2	n	nd^2
6.0	223.5	6847	154.7	5569	135.4	4874
5.5	262·6	6933	181.9	5866	....	....
5.0	314.6	7022	229.6	5740	195.3	4882
4.5	381.9	7047	279.8	5665	246.3	4987
4.0	478.3	6899	359.7	5755	317.1	5074
3.5	....	7371	462.	5668	421.7	5166
3.0	....	....	....	....	842.5	5266
		Mean =6976		Mean =5711		Mean =4996

This variation from the law appeared at first sight somewhat difficult of explanation. On consideration, however, of the results obtained in the previous section, it at once seemed evident that the variation of " n " from the value of it demanded by the law of the inverse square was but another manifestation of the same secondary radiation excited by the presence of the radium in the neighbourhood of the brick wall against which the electrometer was set up.

In Table XII the value of the constant "nd^2 " has been calculated, giving for the receivers of Pb., Zn. and Al. respectively the numbers 6976, 5711, and 4996, which are thus a measure of the ionization in the different cylinders due to the γ rays from radium plus the secondary rays induced by them in the enclosing metals. These numbers we see are in the ratio of 1.4 to 1.14 to 1.0 for the three metals Pb., Zn., and Al., whereas the ratios arrived at from the figures of Table XI

for the corresponding effects due to the earth's radiation were 1.1 to 1.23 to 1.00. The considerable difference beween these ratios would thus seem to indicate a difference in penetrability between the γ rays from radium and the penetrating radiation from the earth. It is possible, however, that the discrepancy may have had an entirely different origin and further measurements should be made to ascertain the cause of it before a satisfactory explanation can be offered.

VII.—Experiments on Absorbing Power of Water.

From the foregoing experiments with radium in conjunction with the effect noticed in IV c., we see that there was in each case some additional effect inside the cylinder which must be considered as due to the presence of the wall. From these experiments the idea presented itself that possibly the earth's penetrating radiation was the same at all points on its surface, and that the differences observed in the values for "q" for the land and water experiments were due not so much to differences in the absorbing power of the different soils as to differences in a secondary radiation induced in the crust of the earth by this penetrating radiation.

To determine if any effect of this kind could be noted in the case of water for the penetrating rays from radium, the sample used in the investigation described in Section IV was lowered under the ice on Grenadier Pond, and the ionization noted in a lead cylinder placed above it for different depths of the radium. In making these measurements the radium was hermetically sealed in a glass tube, which was then enclosed in a tube of brass, whose walls were 1 cm. in thickness.

The results (Table XIII) shewed that 2 metres of water completely cut off all effect from the radium—both primary and secondary, the same being illustrated by the curve in Fig. 9.

TABLE XIII.

Cylinder 113 cms. above ice.

Depth of water over radium = d.	Number of ions due to radium = "n."
0 metres.	4485
½	447.2
1	16.11
2	.69
3.65 at bottom	.62

This result, surprising as it at first sight appeared, is exactly what one would expect from a consideration of the values of Table XI, which shew that practically the same value for the ionization was obtained over water of depths ranging from 2.5 to 10 metres. Owing also to this fact that complete absorption of the γ rays from radium took place it is clear that over the water of Lake Ontario, at least, there is no appreciable secondary effect due to the earth's penetrating rays, such as has been shewn to be emitted by a brick wall under bombardment by the γ rays from radium.

Since, in addition, we know from an observation made by Prof. McLennan, that the waters of Lake Ontario contain no appreciable radioactive emanation, the conclusion is forced upon us that in the case of the experiments described above with the cylinders of lead, zinc, and aluminium, the water of the lake acted as a perfect screen for the earth's penetrating radiation, and the values of "q" recorded in Table XI for Observation Station No. 2 may be taken to represent the conductivities impressed upon the air either by intrinsic radiations arising from the metals of the receivers themselves, or else by radiations from active impurities still remaining in them.

Taking in the case of the lead cylinder the value of 8.6 ions per cc. per sec., as due to intrinsic activity, we have a means then of calculating the ionization in this cylinder, due to the soil alone in any position on the surface of the earth.

From the value of 11.1 ions obtained with the lead cylinder over clay (given in Table XI) a calculation shews that 2.6 ions per c.c. per second in such a cylinder is due to the soil alone. If now we assume, as seems justifiable from the experiments of Professor McLennan, *loc. cit.*, on the conductivity of air enclosed in lead receivers, that the ratio of the ionization due to the secondary rays in a lead cylinder of the dimensions of those used in this investigation, is twice that due to the primary, it follows that approximately 0.9 ions would be generated in free air over a clay soil by the earth's penetrating radiation in the localities referred to above.

On the basis of Strutt's determination of the radium content of the rocks and soils, Strong[1] has recently deduced a value of 0.8 ions as an upper limit for the ionization in free air due to the penetrating rays from radioactive substances in the soil, and this number it will be seen is in good agreement with the experimental result obtained in this investigation.

In passing, it might be noted that this calculation throws some light on the results obtained (Table VI) for the regular daily variation,

[1] Strong, Phys. Zelt., 9, pp. 117-119, Feb. 15, 1908.

which it will be remembered was found to be inappreciable, and which is exactly what should be expected if only some two or three of the ions generated in the cylinder per c.c. per second were due to a penetrating radiation from the earth.

VIII.—Summary of Results.

The results obtained in the preceding investigation may be summed up as follows:—

(1) No evidence of a regular daily variation was noted.

(2) It has been shown that there is a penetrating secondary radiation set up by penetrating rays such as those from radium, in the brick wall of a room.

(3) Proofs have been adduced to show that the water of Lake Ontario acts as a perfect screen, both for the earth's radiation and if a sufficient depth be taken, for the γ rays from radium. On this account, and owing to the fact that the water of Lake Ontario contains no active impurity, it has been possible to determine what portion of the ionization in the receivers used in this investigation was due to residual active impurities and to intrinsic activity in the metals of the receivers.

(4) Based on this fact, a determination has been made of the ionization in free air due to radioactive impurities in a clay soil, and this value, 0.9 ions per c.c. per second, has been found to be in close agreement with a value deduced by Strong from Strutt's determination of the radium content of the earth.

(5) The ratio of the ionization in cylinders of lead, zinc, and aluminium due to the radiations from the earth has been determined and has been found different from the ratio for the ionization due to the gamma rays from radium,— a result which needs confirmation, but which points to a difference in the penetrability of the two radiations.

(6) The values obtained in the open for the ionization in well cleaned receivers of lead, zinc, and aluminium, are lower than any hitherto recorded, the numbers 8.6, 6.0 and 6.5 respectively being obtained over the water of Lake Ontario.

Considered as a whole, the experiments described above are interesting from the light which they throw on the question of the radioactivity of metals and substances generally. The values obtained for "q" for the three cylinders at Station 2, Table XI, differ from each other but little. They are, moreover, of the order of magnitude of effects which might easily be accounted for by active impurities in the metals, since differences as large as these values of "q" may easily be

obtained with cylinders made from different samples of almost any metal selected at random. Considering also the difference in the atomic weights of the three substances, aluminium, zinc, and lead, and having in mind that radioactivity is a property associated with atomic structure, it would seem that if these metals could be obtained entirely free from active impurities, and the conductivity of air contained in vessels made from them studied, it would be found, if the observations were carried out under conditions, or in places where no ionization was possible from penetrating radiations arising from external sources, to drop to a very low value if it did not entirely vanish.

In conclusion I desire to thank Professor McLennan, both for his valuable suggestions and for his assistance at all times throughout the investigation.

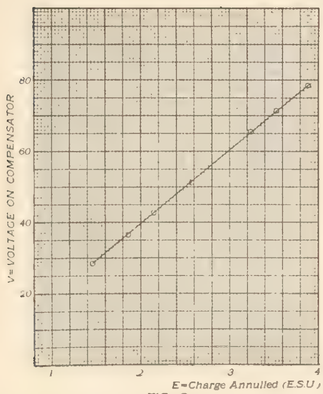

FIG. 3

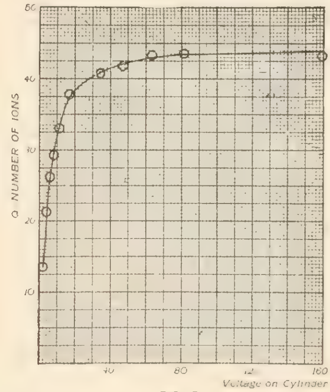

FIG. 5

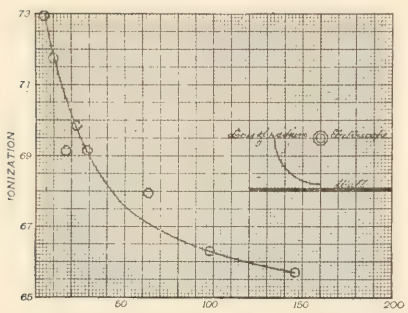

FIG. 6

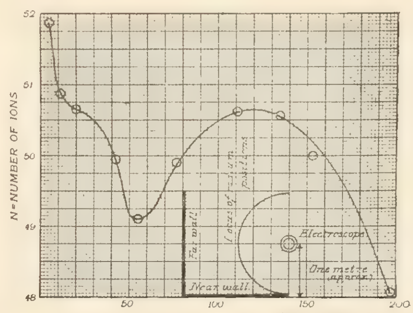

FIG 7

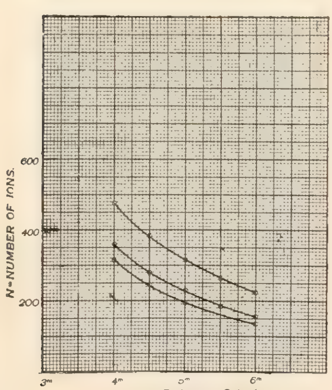

FIG. 8

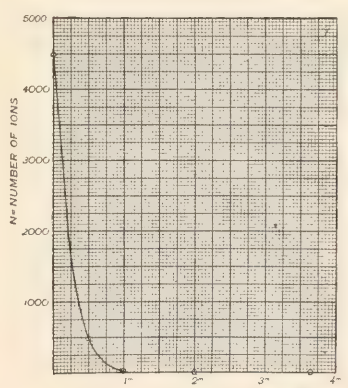

FIG 9

UNIVERSITY OF TORONTO STUDIES

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